Outline

- Deep Drawing
- Deep drawing analysis
- Other Sheet metalworking operations
- Formability of Sheet Metal
  - cupping test
  - bulge test
  - forming-limit diagram
  - tension tests
    - normal anisotropy
    - planar anisotropy

Deep Drawing

- Sheet metal forming to make cup-shaped, box-shaped, or other complex-curved, hollow-shaped parts
- Sheet metal blank is positioned over die cavity and then punch pushes metal into opening

Steps:
- Initial contact
- Bending
- Straightening
- Friction and compression
- Final shape

Products:
- beverage cans, ammunition shells, automobile body panels

Deep Drawing

Significant Variables
- Properties of sheet metal
- Ratio of blank diameter to punch diameter
- Sheet thickness
- Clearance between the punch and the die
- Punch and die and corner radii
- Blankholder force
- Friction and lubrication at the tool/workpiece interface
- Speed of the punch

Failure results from thinning of the cup wall
Deep Drawing: Variables and Defects

During drawing, when the blank moves into the die, compressive circumferential stresses are induced in the flange.

- This causes flange to wrinkle
- Eg: try forcing a circular sheet of paper into a drinking glass

Die radius too small
Punch radius too small

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Deep Drawing: Variables and Defects

- Low carbon steels exhibit this behavior
- This produces lueder’s bands (stretch strain marks)
- These marks can be eliminated by reducing thickness of sheet from 0.5% to 1.5% by cold rolling process

Grain size: mechanical properties and surface appearance are affected by the grain size. The coarser the grain the rougher the appearance. (Orange Peeling defect)

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Analysis of Drawing

Measure of Drawing:
- Drawing ratio: \( DR = \frac{D_b}{D_p} \) feasible if \( DR < 2 \)
- Reduction \( r = \frac{D_b - D_p}{D_b} \) feasible if \( r < 0.5 \)

Crude measures of the severity of a deep drawing operation

Drawing Forces:
\( F = \pi D_p t (TS) \left( \frac{D_b}{D_p} - 0.7 \right) \) Max at 1/3 length

Holding Force:
\( F_h = 0.015Y \pi \left[ D_b^2 - \left( D_p + 2.2t + 2R_d \right)^2 \right] \)

Clearance in Drawing:
\( c = 1.1t \)
where \( t \) = stock thickness
- In other words, clearance = about 10% greater than stock thickness

Thickness-to-Diameter Ratio:
Desirable for \( t/D_b \) ratio to be greater than 1%

- As \( t/D_b \) decreases, tendency for .......... increases

Blank Size Determination:
- For final dimensions of drawn shape to be correct, starting blank diameter \( D_b \) must be right
- Solve for \( D_b \) by setting starting sheet metal blank volume = final product volume
- To facilitate calculation, assume negligible thinning of part wall
Shapes other than Cylindrical Cups

- Square or rectangular boxes (as in sinks),
- Stepped cups,
- Cones,
- Cups with spherical rather than flat bases,
- Irregular curved forms (as in automobile body panels)

*Very important commercial process.*

Each of these shapes presents its own unique technical problems in drawing.

Other Sheet Metal Forming on Presses

- Makes wall thickness of cylindrical cup more uniform

Examples: beverage cans and artillery shells

Used to create indentations in sheet, such as raised (or indented) lettering or strengthening ribs

Other Sheet Metal Forming on Presses

- Low tooling cost
- Form block can be made of wood, plastic, or other materials that are easy to shape
- Rubber pad can be used with different form blocks
- Process is attractive in small quantity production

Guerin Process

Methods for Reducing the Diameter of Drawn Cups

- Reverse Redrawing
- Conventional Redrawing

Redrawing

A method to reduce the diameter of drawn cup
Steps in Manufacturing an Aluminum Can

Hemming Process

- The edge of the sheet is folded over itself
- This increases stiffness of the part
- This method is now used in the automotive industry to join an outer part and an inner part.
- The metal strip is bent in stages

Defects during hemming: Springback, Fractures and Wrinkels in the flange

Formability of Sheet Metals

- Earliest tests developed
- Simple to perform
- ................. indicator of formability
- Do not simulate exact conditions of actual operations, WHY?

Bulge Test

- Bulge-test results on steel sheets of various widths.
- The specimen farthest left is subjected to, basically, simple tension.
- The specimen farthest right is subjected to equal biaxial stretching

➢ It has been used extensively to simulate sheet forming operations
➢ Hydraulic pressure is used instead of punch ⇒ stretch forming without friction
➢ it is used to obtain effective-stress vs. effective-strain curves for biaxial loading under frictionless conditions
Major Strain and Minor Strain

- During stretching in sheet metal, Volume constant
\[ \varepsilon_l + \varepsilon_w + \varepsilon_t = 0 \]
- Major strain always larger than minor strain
  - Major strain \( \varepsilon_l \) \( > 0 \)
  - Minor strain can be either positive, negative or zero

- Plane strain
  - Minor strain is 0
  \[ \varepsilon_l + \varepsilon_w + \varepsilon_t = 0, \text{ thus } \varepsilon_l + \varepsilon_t = 0 \]

Forming Limit Diagrams

The deformation of the grid pattern and the tearing of sheet metal during forming. The major and minor axes of the circles are used to determine the coordinates on the forming-limit diagram.

Although the major strain is always positive (stretching), the minor strain may be either positive or negative or zero.

Forming-limit Diagrams (FLD)

- More a research/development tool than a practical (quick) test
- Time consuming to perform
- Represents .......... forming operations reasonably well

Tension Tests

- The most basic and common test used to evaluate formability
- It determines important properties of the sheet metal such as:
  - total elongation of the sheet specimen at fracture
  - strain hardening exponent
  - the planar anisotropy, and
  - the normal anisotropy

Normal Anisotropy

- Normal anisotropy: \( R = \varepsilon_w / \varepsilon_l \)
  - Remember: \( \varepsilon_l + \varepsilon_w + \varepsilon_t = 0 \)
  - Simple tension, \( R = 1.0 \)
- Determines thinning behavior of sheet metals during stretching; important in deep-drawing operations
- Tensile tests determine normal anisotropy

Strains on a tensile-test specimen removed from a piece of sheet metal. These strains are used in determining the normal and planar anisotropy of the sheet metal.
**Average Normal Anisotropy**

\[ R_{\text{avg}} = \frac{R_0 + 2R_{45} + R_{90}}{4} \]

**Average Normal Anisotropy Vs Limiting Drawing Ratio**

- Limiting Drawing Ratio (LDR) = \( \frac{D_0}{D_p} \)
- Where, \( D_0 \): Maximum Blank diameter
- \( D_p \): Punch Diameter

**Planar Anisotropy (Earing Tendency)**

\[ \Delta R = \frac{R_0 - 2R_{45} + R_{90}}{2} \]

- Planar anisotropy causes ears to form in drawn cups
- When \( \Delta R = 0 \), no ears form
- The height of the ears increases as \( \Delta R \) increases
- Number of ears: 4, 6, or 8
- For better deep drawability: \( R_{\text{avg}} \) ↑ and \( \Delta R \) ↓
  
*These values.*
Earing and Planar Anisotropy

Effect of Planar Anisotropy on Earing

\[ \Delta R = \frac{R_w + R_{tt} - 2R_{wtt}}{2} \]

\[ R = \frac{\varepsilon_w}{\varepsilon_t} \]

Next time:
Continue Sheet Metal Forming